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NOTES ON THE 1916 ERUPTION OF MAUNA LOA

HARRY O. WOOD
Hawaiian Volcano Observatory

III

The writer spent the two days and night of May 30 and 31, 1916, in making a hurried reconnaissance of the Kahuku branches of the recent flow, and of the region near its source, where action was still going on, though the eruption already had greatly diminished. There had been no forward movement of the flows at their fronts later than May 27 or May 28. A preliminary account of this work was published at once in the *Weekly Bulletin* of the Hawaiian Volcano Observatory.¹ However, difficult foot traveling was encountered, and somewhat adverse weather conditions, which prevented thorough and accurate work; and the presence of fog and fumes led to erroneous estimates of distances and heights; also, our guide applied place-names incorrectly and his errors naturally found place in the early report. Further, observations of much interest, but not pertinent to the present subject, were included in that account. Hence an abridged and corrected statement relating to the 1916 action finds appropriate place here. Much that was only glimpsed on this hurried trip was fully confirmed by the later study. Whence certain observations thus confirmed it is convenient to mention here.

ITINERARY

The writer and one companion left the observatory in the early evening of May 29 and motored to the village of Waiohinu, where the night was spent. Early the next morning we motored to a gate of the Kahuku ranch about a mile west of the ranch buildings. Here we were joined by the guide, and the party set out on horseback at 8:00 A.M., going up the south slope of the mountain between

¹ Vol. IV, 6, pp. 51-57.

the flows of 1868 and 1887. At 10:30 A.M. we reached the southernmost "toe" of the front of the Kahuku branch of the 1916 flow. Here we turned off to the right to pass around this flow and up on the east and north of it. We followed an upland trail toward Kapapala until we came into a *Kipuka*, a long, narrow strip of forest land extending up the mountain between two barren streams of *a-a*, known by the name Kipuka Akala. At the lower end of this we left our horses. We reached it shortly before noon, and at noon we set out on foot up the mountain, taking a northwest course toward the general source of the new flow, north of the conspicuous cluster of cinder cones marked Puu o Keokeo on the government map. (There is dispute as to whether this name is correctly applied to this group of cones, but there is no doubt that the members of the group so mapped were those identified.)

As we planned to spend the night near the source we were necessarily laden with food, water, photographic equipment, etc., and blankets or extra clothing—a moderate load for each man. For about an hour we made our way upward alongside the strip of forest, but walking in the open chiefly over old *a-a*. At about 1:00 P.M. we came out onto a barren, complex network of *a-a* flows of varying direction and age—much of this apparently of 1907 date—and over this very difficult surface we clambered until a little after 5:00 P.M. We then had reached an old cinder cone situated between two and three miles from Puu o Keokeo in a direction a trifle east of north. This cone was about a quarter of a mile east from the rift-line source of the 1916 flow described below. We had not reached the upper limit of this source, which had been our goal, but it became impracticable to go on farther. Here we stationed ourselves in the lee of this old cinder cone and passed the night, practically all of which the writer devoted to observation of the action and conditions along the visible length of the rift source.

At 4:50 A.M. on May 31 we began the descent. At 9:40 A.M. the horses were reached, and at 10:15 A.M. we started on our way to Puu o Keokeo, going around the southern end of the Kahuku branches of the flow and up on the western side of them. By noon we reached a flat clearing, where we dropped our camp equipment

and immediately proceeded upward on horseback to a point very near to Puu o Keokeo, on a low ridge of ancient pahoehoe which extends a short distance eastward from the conspicuous cluster of cinder cones. In clear weather this slight eminence affords an expansive view to northward, and much wider views can be obtained from the summits of the cones near by. On this occasion we obtained only partial views through driving fog and clouds, and in brief clear spells between small local showers. We reached this point of outlook at 2:20 P.M. It was impracticable to keep horses here overnight, and unnecessarily uncomfortable to remain ourselves without camp equipment in such unsettled weather, especially as our hasty reconnaissance was completed, so we began our descent at 2:35 P.M., and returned on horseback to Waiohinu, which we reached at 8:30 P.M. We returned to the observatory the next day.

Thus we passed completely around the Kahuku branches of the new flow, except for their breadth near the source. In this way, especially on the foot journey, and also from the ridge near Puu o Keokeo, a good general survey was obtained of conditions along these and near their source; and in limited localities, particularly those encountered on foot along the eastern side of them, many matters of detail were observed. Conditions of the traveling, distance, and weather prevented examination of the upper limits of the source, of the action and conditions on the sides toward Kona, and the making of photographic records.

GEOGRAPHICAL NOTES

The closely grouped cluster of old cinder cones, named Puu o Keokeo on the government map, of which the highest point is 6,870 feet above sea-level, forms a low but conspicuous landmark on the south-southwest flank of Mauna Loa. Extending east-southeastward from this for a half-mile or less is a low ridge of ancient pahoehoe rising from 30 to 50 feet above the surrounding country.

A long narrow belt marked and characterized by many cinder cones (double semicones built by spatter outfall on both sides of open rift cracks in parallel linear arrangements) leads upward in a

practically straight line from a point a little west of this conspicuous group to the summit plateau of Mauna Loa (see the photographs, Plate VI, *a* and *b*). North of this lava ridge and east of the belt of cinder cones (and to a less extent west of it also) is a comparatively flat area. For a considerable distance to the northward toward the summit, the surface of this stands at a lower altitude than the summit of Puu o Keokeo, and its eastward extension from the belt of cones, though variable, has a width of from two to three miles. This makes a very conspicuous upland flat of very slight grade on a broad dome surface which is itself of very gentle slope. South of Puu o Keokeo the usual slope of the mountain is resumed. At the southeast and east this broad, irregular flat passes imperceptibly into the irregular, broken slope of the dome. Several miles to the north of Puu o Keokeo the flat passes rather quickly, though the region of transition is indefinite, into the somewhat steeper slopes which rise to the summit plateau. Viewed from the ridge south of this flat, Mauna Loa appears as a distinct mountain until the genetic significance of the long belt of cones is understood (see the photographs, Plate VI, *a* and *b*).

This belt of cones marks an unmistakable major rift zone, which joins at the summit with that leading down the northeast flank of the mountain—a great crust fracture, as a whole slightly curved and convex to the northwest, through the whole dome of Loa. This stretches northward across the flat and bounds on the west that part of it seen on this reconnaissance.

SOURCES OF ERUPTION

As was anticipated, the sources of the eruption of 1916 were found to lie in this major rift zone. Both the sources of earliest outbreak, high on the dome, and the sources of flow lie in it. Both were seen to constitute segments of the rift zone, and to be themselves rift traces in this zone.

THE SOURCE OF EARLIEST OUTBREAK

A long fissure marked by constant emanation of steam (or fumes) was seen leading from near the summit plateau of Mauna Loa down the south-southwest side of the upper slopes of the dome

nearly to the region where this grades into the great flat—a distance of several miles (see the photographs, Plate VI, *a* and *b*). For the most part the steam was clinging to the surface along the line of fissure; but at one point (and possibly a second) it was rising definitely in small volume. Unquestionably this eruption marks a minor rejuvenation in 1916 of the action of rifting through Loa, and in this upper segment were the orifices, large and small, from which came the outrush of fumes in the morning of May 19. The place, or places, where steam appeared to be rising definitely was well up the slope beyond its transition into the flat. The line of fissuring marked by steam emanation possibly is interrupted, and perhaps is offset *en echelon*. This could not be determined positively when seen from so considerable a distance. This fissure leads down in line with the primary system of double semicones which stretch across the flat along the rift zone from near Puu o Keokeo. This line of new steam emanation was seen definitely at all times when the upper slopes were in the field of vision.

THE SOURCE OF FLOW

The source of flow was found to be a freshly opened rift crack or, more precisely, a long, narrow system of closely spaced parallel cracks. This ran in a direction slightly oblique to that of the broad rift zone, but confined well within the limits of it, for some three miles or more, tending very slightly to the west of north from Puu o Keokeo across the flat toward the summit. Its upper limit was not reached on this reconnaissance. Out of these fresh cracks gushed the molten lava which streamed away toward lands in Kona, and toward Kahuku—the streams dividing at the northern base of the group of old cinder cones at Puu o Keokeo. Only the Kahuku branches were seen on this reconnaissance.

OBSERVATIONS NEAR THE SOURCE

Our bivouac for the night of May 30–31 was in the lee of an old triple-peaked, double semicone in the south re-entrant, where its parts straddle an ancient cinder-choked fissure. This cone was elongated in the north-south course of this fissure. It had been the source of an ancient eruption of pahoe-hoe. This station was

between two and three miles from Puu o Keokeo in a direction a trifle east of north. Just west from here, about a quarter of a mile away, was one of the two larger cinder cones of 1916. This was a double semicone built on either side of the new rift crack. Both north and south of this new cone were several other new cones. A flow of *a-a*, undoubtedly of the date of 1907, separated us from the line of vent of the latest activity.

Though greatly diminished, there was still vigorous action at many points along this line. At first the most active point was a cinder cone near the northeastern base of Puu o Keokeo, between two and three miles almost due south of us (see the photograph, Plate VI, *d*). Though this was down the wind, which was gentle, however, explosive coughing sounds could be heard at frequent irregular intervals; and occasionally red-hot masses were thrown up into our field of vision. This action continued throughout the evening and the early part of the night. During this interval the glow above this vent was considerable, though less than that ordinarily seen above Halemaumau as viewed from the observatory at about the same distance (yet, through the disturbed air, it appeared to be comparable with this). However, at about 8:45 P.M., May 30, a short, sharp earthquake occurred, plainly felt by all three of us sitting or reclining on the cinders in the fissure re-entrant of the old cone. (This shock was felt sharply at Waiohinu and at Kapapala. At Hilea it was felt as the strongest shock of the entire series connected with this eruption.) Within less than a minute, but more than thirty seconds, after this shock there occurred a spasm of greatly increased action at the vent mentioned, with the jetting of lumps of incandescent lava high in the air, and a great increase in the glow. However, the action again quickly subsided to normal. Afterward the action at this vent declined, at first slowly, but toward 1:00 A.M., May 31, more rapidly. By 3:00 A.M. the situation of this vent could barely be made out. When seen again in midafternoon, on May 31, from near Puu o Keokeo, only a smoking cone appeared. There was no revival of activity afterward, so doubtless we witnessed the dying of action at this vent.

In the late afternoon of May 30 a glowing cone was seen, showing an oven-like orifice, situated at a distance of two hundred

to three hundred yards to the northeast of the vent just described. But after night fell the glow above this was negligible.

Between the new cone directly west of our bivouac and the place of greatest activity just described fumes were rising steadily from numerous larger and smaller vents and cones. After darkness came on three of these fuming places exhibited glow. From our viewpoint this glow came and went intermittently, but this appeared to be due to drifting fog and fumes alternately concealing and disclosing the illuminated fume columns.

The larger new cone just west of our bivouac showed steady, vigorous glow on the fumes at both its north and south extremities. These were separated by a dark interval of about 200 feet. No incandescent matter was thrown from this cone into our field of vision.

To the northwest, at a distance of about a third of a mile—hence probably more than $2\frac{1}{2}$ miles from Puu o Keokeo in a direction a little west of north—was a cone which in some respects exhibited the greatest activity of any of the vents, though it was not conspicuous for glow. Indeed, it was remarkable for the comparatively slight amount of illuminated fumes which appeared to spread from it. By daylight this cone was not seen clearly, owing to drifting fog and fumes; but at night it became plainly visible. It was still building. There were numerous incandescent gashes and glow-spots on its sides which remained without substantial change throughout the hours of the night. These were interpreted as true gashes and orifices in the shell of the cone, through which shone out the incandescent core. Almost incessantly red-hot masses were thrown out of this cone into the air. Most of these barely cleared the summit to tumble and roll down the sides of the cone. The relative motion of these between and among the practically permanent orifices created the illusion of a steady fountain-play of fiery particles high above the summit of the cone, rising and falling like droplets at the top of a jet of water. It required prolonged observation to correct this impression. At intervals of from twenty seconds to three to five minutes, larger masses were projected into the air high above the apex of the cone. These usually would describe free parabolic curves to fall, apparently, beyond the base of the cone. In most of these cases no rolling was seen. At

the time exaggerated estimates were made of the distance of this cone, and therefore of its height, the height of projection, and the sizes of the projected masses. Drifting fog and fumes gave a greatly lengthened perspective effect. Afterward the cone was visited and found to be distant about one-third of a mile from this bivouac, and to be about 30 feet in height. Whence the height of projection of the molten lumps, at highest, was about 45 feet above the apex of the cone, or 75 feet above its base. No large cinder lumps were found about it. Though the cone was situated across the wind from us, a steady, gentle drift of air, loud, staccato, explosive booms could be heard occasionally accompanying the projection of the larger masses. This cone was the most spectacular remaining center of activity of any which came within our range of vision. On the southwest side of it there was an intermittent illumination of the thin fumes, of a sort which suggested outflow of lava coursing away in the southwest direction. However, the later visit determined that this was a spatter cone higher up the rift than the head of flow, and that any flowing from it was very local and confined within a very small area.

Farther north was seen a glowing orifice like an oven which probably was a gash in a quiet cone. Still a little farther up, rising fumes were seen, but these showed no illumination at night. After darkness fell, nine places altogether were distinguished where rising fumes were illuminated. All of these but one were aligned along the rift crack northward from the chief vent at the northeast base of Puu-o Keokeo. The other was the oven, situated a little way to the northeast of this chief vent.

Small quantities of new basaltic pumice, yellow in color, usually in elongate stringers, were found in close proximity to the rift source near its head at the east.

THE KAHUKU BRANCHES

The Kahuku branches of the 1916 flow run in southeast and south-southeast directions from points along the rift source beginning at the base of Puu o Keokeo and extending northward for more than a mile. On our foot journey, on May 30, from 3:00 P.M. on we kept encountering little fuming areas lying to the south of

our route, which indicated the courses of tongues of the new flow. We approached these quite closely as we neared the rift. The trunk of this flow departs from the source at Puu o Keokeo in an east-southeastwardly direction, passing along and around the end of the ridge of ancient pahoe-hoe that juts out from the cluster of cones; there it swerves to the south-southeastward and spreads down the mountain.

Near the source the lava was pahoe-hoe in typical surfaces and in broken crusts and fragments. Except near the source the lava in these branches was *a-a* wherever they were approached closely enough for this to be determined. At points on the east these tongues were thin, from 5 to 10 or 20 feet deep; but at the south and along the west the lava blocks were piled irregularly from 20 to 40 feet deep, or high, and were still hot and fuming on May 31.

In passing from the southernmost point to the eastward and northward many thin, narrow tongues (from 5 to 8 or 10 feet in depth, and from 50 to 200 yards in width) were encountered radiating to the southeast and east. These departed from the main stream at higher and higher points. Wherever junctions were seen the departures of these minor branches appeared capricious; that is, no evidences of local damming or pooling were seen. Though thinner and much less massive than the more western streams, these were still fuming, and in varying degrees the air above them was in a state of shimmer from heat. However, the emanation of the fumes furnished a more reliable indication of their courses than the heat-disturbed air above them. (Probably tongues, or "toes," project from the main streams on the western side, as others report who viewed them before they ceased flowing; we found no opportunity to follow the margin closely and did not note any conspicuous projections.)

Any adequate cartographic delineation of the complex out-branching of this Kahuku part of the 1916 flow can be accomplished only by actual topographic survey. (A reconnaissance survey was made in June, 1916, by a party under the Hawaii Territory Survey. An adapted, and in some details corrected, modification of this follows, as Fig. 1. A general conception of a long, narrow,

branching flow (about $5\frac{1}{2}$ miles long) to the southeast and south-southeast, with many minor spreading tongues, is all that could be developed as a result of this reconnaissance.

When we were in the neighborhood of the new lava, smells of subliming sulphur, sulphur acids, charcoal, and cinders were very noticeable. There were also smoke smells from burning vegetation.

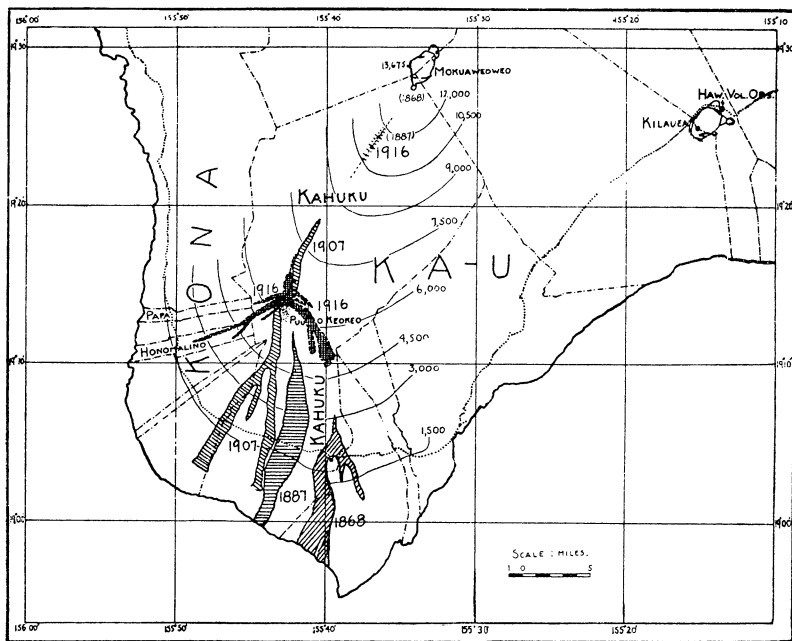


FIG. 1.—A diagrammatic map of the 1916 flow and the neighboring region, adapted from a reconnaissance survey by the Hawaii Territory Survey, June, 1916, with corrections and modifications suggested by field work and reports. This plate also shows a diagrammatic correction of the course of the 1907 flow near Puu o Keokeo.

IV

The thorough exploration of the region of the source of flow made in company with Dr. A. L. Day in late June and early July served to correct or confirm the findings of the hurried reconnaissance made in the last of May, and to enlarge their scope materially. Also many photographs were made, affording a fairly complete pictorial record of the results of the action at the source. However,

our efforts on this occasion were devoted in large measure to observation of details and to the examination of evidence bearing on the physical-chemical conditions and the mechanisms of flowing in the lava streams near their head. The ideas considered in this connection are best left for future discussion by the writer's companion on this expedition. Here it will suffice to say that much was seen tending to confirm, and some things tending to modify, the writer's conception of the mode of flow of *a-a*, as exemplified by the action observed at the front of the Honomalino branch, described above. Consequently, the space here devoted to this more thorough work is small in proportion to its relative importance.

On June 27, 1916, we set out from the observatory and went by motor to Honomalino, and thence with horses up the southeast flank of Loa to a point in Kahuku, above Papa, at an elevation of about 6,500 feet above sea-level. Here we made camp on barren ground a little above tree-line on this part of the mountain, close beside a short narrow branch of the new flow—the most north-western of all its definite branches. The six days, June 28—July 3, we spent in exploration of the source region. On July 4 we returned on horseback to Honomalino and by motor to the observatory.

This camp site was situated on the regular, gentle slope of the mountain dome, between $1\frac{1}{2}$ and 2 miles below the junction of this branch of flow with the rift source. Everywhere here the old surface was of ancient, rusty-red pahoehoe and *a-a* commingled in a complicated pattern—except for an area of gray pahoehoe, younger, but still very old, found about $1\frac{1}{4}$ miles above camp. Nearly all our way upward from camp to the source led alongside the new flow over slopes below the limits of the great flat above Puu o Keokeo, but as the 1916 source was closely approached these slopes graded into this upland plain west of the new rift cracks.

The sources of all the branches of the 1916 flow lie in the new rift segment. The 1915 rift here is a newly developed fissure, or in most places a very narrow system of closely spaced fissures (the primary group together nowhere more than 30 feet wide and nearly everywhere much narrower) which extends from the northern base of Puu o Keokeo for a distance estimated closely at $3\frac{1}{2}$ miles in a

direction almost exactly magnetic north¹ (see Plate VI, *a*). This fissure, or system of fissures, is practically uninterrupted and, except for a short curving segment at the north end (see Plate VI, *c*), it follows a straight line. It lies wholly within the limits of the great rift zone, but its course is slightly oblique to the general trend of that, which is about N.N.E. (see Plate VI, *b*), and this suggests a major shear through the mountain. It ends on the north at an old red cinder cone at an elevation of about 7,480 feet above sea-level, while at the south its point of interception with Puu o 'Keokeo is at an elevation of about 6,600 feet (see maps, Plate I and Fig. 1).

Besides this chief rectilinear fissure, or primary group of fissures, there are a great many secondary cracks, running roughly parallel with the system, especially on the west; on the east there are few. Many of these opened *after* the chief outpouring of lava was over, for they traverse the fresh flows. (It is notable, moreover, that earthquakes continued to increase in number and energy until after the eruption began to decline definitely.) Many, however, traverse the older surface neighboring the source; and here they appear as consistent extended fissures in the more or less solid basalt of the mountain, but also there is noted a tendency for the fissuring to be continued from one crack to another through offsets *en echelon* (see Fig. 2).

Though miniature dislocations have resulted necessarily, there is no observable tendency to any general vertical dislocation; but the repeated evidences of offsets *en echelon* strongly suggest a general horizontal shear. There are, however, no sufficiently well-indicated and extended landmarks, surface features, or structure lines to afford a real test or proof of this. Where these cracks traverse the old surface and where they *cut* the new flow, there generally is no evidence of gas outrush, bulging, or fumarolic action, or any evidence of heat emission.

Altogether, as study progressed the conviction gained force that the amount of rending of the mountain dome here seems out

¹ The general magnetic declination in Hawaii is about N. 10° E., but large local variations make the application of corrections so uncertain that the direct magnetic reading is given here by preference.

of all proportion, either to the outrush of imprisoned gas from this vent (for gas emission throughout the flow was apparently small in volume and relatively very quiet), or to the momentum-pressure of the outpoured magma. Also, the features of the rifting and their distribution appear to differ from those that should be expected to result from such causes. (Resemblances of this action to fissure-eruption phenomena in Iceland are noted below. See especially Plate VI, *c*, and Figs. 2 and 3.) Moreover, as just mentioned, great numbers of weak to moderately strong local earthquakes were registered at the observatory 30–35 miles from the source of action, the energy of these *increasing* even after the cessation of forward movements of the flow, but while the vents at the source



FIG. 2.—A panoramic view looking N.N.E., showing the old red cinder cone riven by new cracks, and the solfatara at the head of the new rift (the figures of the men give scale); and black lava, of 1907, at the base of the cone, which is a little over 100 feet high.

were still freely open. Several of these were felt definitely over a considerable area, having a radius of much more than 30 miles; and one or two of these were quite sharp at the observatory. The question of their origin will be discussed in a later paper.

In brief, for many reasons the conception that this eruption was, in part at any rate, *primarily* a *tectonic* event must be examined thoroughly and not put lightly aside. No very violent action was observed or suggested, nor any such as would be expectable were a rift like this to be produced by explosive forces, or by upthrust from a confined substance tending to expand rapidly or seeking immediate outlet to the surface—as volcanic potential usually is

hypothesized. The lips of the rift were not outforced or uplifted, nor were radial cracks produced. Such action of lava and gas out-rush as was observed would be expectable if eruption were *permitted* through tectonic rending of the mountain shell in a manifestly weak zone, thus unsettling the physical-chemical equilibrium of the gas-charged magma afforded exit to the surface and the atmosphere in this way. Many of the eruptions of Mauna Loa have exhibited similar peculiarities, perhaps most of those observed. This whole aspect of eruption here deserves a much more thorough discussion than can be given it in this paper. However, to the mind of the writer, the phenomena of the 1916 eruption appear to illustrate admirably the conception so clearly stated by Geikie,¹ if only the expression "tectonic strain" be substituted for his phrase "terrestrial contraction," with the emphasis in this instance on tectonic strain as a cause.

The fact that some of the circumstances of this eruption might be interpreted adversely to this view may be discussed more advantageously in a systematic study of the seismic accompaniment. Altogether this conception deserves careful attention. Of course, it must not be considered to invalidate or displace views developed from, and applied to, other modes of eruption in other lands, but it must not be rejected simply because it is different from them. Moreover, there is no disposition to overlook the very real application of more commonly recognized modes of eruption in this recent outbreak, or in other eruptions in Hawaii. It is intended merely to give this tectonic mechanism emphasis and to point out its possible, or probable, local predominance.

Lava did not well out of the new rift along its whole length. Hence we may subdivide it, recognizing two segments: a longer flow-source segment, and a shorter solfatara-spatter-cone segment stretching on up the mountain beyond the head of flow.

THE FLOW-SOURCE SEGMENT

For about $2\frac{1}{2}$ miles from Puu o Keokeo in a direction about N. 3° W. mag. the new rift is indicated by a system of open fissures straddled by seven double semicones, varying from 20 to 100 feet

¹ *Ancient Volcanoes of Great Britain*, I, 10-13.

in height and from 50 to 200, or more, feet in the length of the greater diameter, built of pumice, cinders, and spatter outfall—these are also primary sources of flowing streams—with many smaller cones and mouths intervening. The resemblances of these cones and fissures, and their interrelationships, to features in Iceland—especially along the great Laki fissure—as described by Geikie¹ and those from whom he drew, and as exhibited in the views by Anderson reproduced by him, is very striking indeed; few would



FIG. 3.—A view looking north into the gash of the second largest cone of 1916, situated a little south of the head of flow. Its character as a double semicone, built of ejected products, and the channel of outflow from the gash are shown. This cone is about 70 feet high.

question that the course of action was similar in both regions (see the photograph, Fig. 3, especially). Moreover, at practically all points along this segment lava welled out and flowed on both sides of the open rift in southeast, south, or southwest directions down along the course of the fissure system and out along narrow, jutting tongues of greater or less length, as well as down the greater streams. One of these, the largest, led toward Kahuku (see the photograph, Plate VI, *d*), and three others led toward

¹ *Op. cit.*, II, 260–65, Figs. 292, 293.

Kona, two of which were relatively small, though not to be mistaken for tongues. Of all these greater streams the Honomalino branch was longest (see the map, Fig. 1).

At its upper end the area of the new flow is narrow, varying in width up to a third of a mile, and elongate parallel to the rift; its margins here are irregular and lobate on a small scale..

THE SOLFATARA-SPATTER-CONE SEGMENT

For a mile above the head of outflow the open-fissure system continues, at first in a direction about N. 3° W. mag., but in its last third it curves gently eastward, so that the direction from the foot of the flow-source segment to the head of this upper segment is N. 2° W. mag. It is marked by an almost continuous line of fresh solfataric action along which, in numerous protected niches, very delicate, feathery, sulphur crystals were subliming in considerable quantity, apparently in unusually pure aggregates (see the photographs, Plate VI, *b*, *c*). This action, and also all conspicuous fissuring, ended in the flanks of an old red cinder cone, whose summit is about 7,480 feet above sea-level and its base 7,375±, which stood directly in the course of the major rift belt not far from its western margin.

Also there were observed along this segment three new spatter cones, the largest 30 to 40 feet in height, wholly isolated from the area of continuous flow; and several small spatter mouths, one of which was situated very near the upper end of the segment at an altitude of 7,370 feet above sea-level.

Near their head the new flows are thin pahoehoe, either in smooth sheets traversed by rift cracks of *later* origin, or, more commonly, broken and torn crusts of pahoehoe transported and piled into an irregular and confused surface (see the photographs, Plate VI, *d*, and Fig. 4). Near the edges of flow, and the edges of festooned flow channels, rough, *a-a*-like textures are seen in all intermediate phases between "pulled" pahoehoe and cindery *a-a*. Down their courses the flows become thicker and their surfaces more irregular and fragmented, passing finally, within a mile or two, through slaggy phases, into unmistakable

cindery *a-a*. These flows spread indiscriminately over the various materials of the old surface and near-by areas of the lava of 1907.

At and near the sources the following types of new lava were observed:

a) PRODUCTS OF FLOW

Pahoehoe, which here exhibits various surface textures determined by the interrelationships of different conditions during the progress of flowing, such as the degree of viscosity (dependent in part upon the temperature, the gas content, its state of solution,



FIG. 4.—A view looking southeast, showing the cone at the head of flow, thin, fresh *pahoehoe* spread over old *pahoehoe* and *a-a*, and the south terminal of the line of solfataras. This cone is from 15 to 20 feet high.

the amount of the crystalline content, etc.), the mass, and the gradient of the surface, all these influencing the rate and manner of flow and the consequent action of subsurface traction on the crusts.

Textures

Pumiceous texture, a finely vesiculated spongy surface very closely resembling basaltic pumice in color and structure.

Lacy texture, a more coarsely vesiculated spongy surface modified by flow tractions so as to resemble patterns of complicated lacework.

Ordinary textures, comprising surfaces of varying character and degree of vesicularity, and surface vesicle patterns, difficult to illustrate or describe except at great length, but common in all fields of pahoehoe.

"*Pulled*" texture, seen in incipency in the lacy texture, but extended to most of the ordinary types wherever, through continued traction, the surface was greatly sheared after it had stiffened or partially set. This gave rise to stippled and bladed surfaces, and to actually fragmented surfaces, so thus, by degrees, it passed over into a slaggy *a-a* texture.

The textures most prevalent in the source region were the pumiceous texture and the "pulled" texture.

Slag, a product of flow made up of rough fragments varying in size and in character from torn and wrapped pahoehoe crusts to cindery *a-a* lumps.

In a general way, here slag was characteristic of the flow channels near the source and of an intermediate region down the flows between the typical pahoehoe and *a-a* stages.

A-a, rough-surfaced block lava, typical of by far the greater part of all the 1916 branches of flow.

b) EJECTED PRODUCTS

Basaltic pumice in three distinguishable varieties which, of course, grade into each other: (1) a very finely vesicled variety of light-yellow color, almost a thread-lace scoria in structure; (2) ordinary yellow to brown basaltic pumice, with fused surfaces, resembling pulled molasses candy; and (3) a more coarsely vesiculated brown to black pumice which grades with the increasing size and the decreasing numbers of vesicles into

Cinder lumps, which, in turn, grade with decreasing vesicularity and increasing density into

Slag lumps, (1) some of which exhibit a surface like obsidian; (2) others a surface like *a-a*.

All these were observed all along the rift and about the spatter cones, but the pumice phases were very abundant near the south

end and around the major cones (see the photograph, Plate VI, *d*), while slag lumps were more characteristically found about the spatter cones and along the northern part of the rift course.

Also there was suggestion that the ejection of slag lumps continued after the action of pumice ejection was over, but no *proof* of this could be elicited.

DISTANT OBSERVATION OF THE UPPER SOURCE

The upper source of the 1916 eruption, where the outbursts of fumes occurred on May 19, has not yet been visited, so far as the writer is aware. This is a place on the great mountain dome very remote from trails, and travel with horses over the barren, untracked lava is both difficult and dangerous. This source lay between 13 and 15 miles from our camp—a distance altogether too great to cover on foot in the short time at our disposal over going so rough as that prevailing within and along the rift belt.

However, this region could be seen plainly through the clear mountain air from the old cone at the head of the lower rift, at a distance of a little over 9 miles. With binoculars magnifying eight diameters some of its characteristics could be made out. It lay within, and was much elongated parallel to, the axis of the major rift zone. It extended from near the edge of the summit plateau down the somewhat steep upper slope nearly to the great flat which lies north of Puu o Keokeo. It appeared to have a moderate breadth, say a quarter of a mile. Fumes were clinging, or slowly rising, along its axis, probably from a system of fissures (see the photographs, Plate VI, *a* and *b*). In two places, apparently not far apart, about two-thirds of the way up its course, definite columns of rising fumes could be made out frequently. On one occasion, in the late forenoon of July 3, one of these columns was estimated to reach upward 500 feet before it spread out and dissipated.

At all times when it was clearly visible the surface of this source area, on both sides of the line of fumes, appeared of very light color, even whitish. It could not be determined whether this was due to the sheen of new pahoe-hoe, to efflorescence of sulphur or

sulphur salts, or to the escape of fumes in very small quantity from numerous cracks distributed over the area. No other explanations of this light color suggested themselves.

Cones of medium size could be seen within the area. Fumes were rising from them and around them. It is uncertain whether these were new cones, or old cones freshly riven. In general, here, eruption does not take place through old fissures reopened; but exceptions are known. There was no great amount of action at night at this upper source. However, the fuming action in the cleft and on the sides of one of these cones strongly suggested that it was of new origin.

Certain features of older origin, found in the neighborhood of the lower source, claim bare mention here.

Above Puu o Keokeo there is a long, narrow flow of fresh, black *a-a* (with long narrow tongues projecting from it over the great flat to the eastward), which stretches along the eastern margin of the 1916 flow source, and in part lies under the 1916 outflow. This begins much farther up the mountain, in the course of the rift, than the 1916 head. Undoubtedly this is lava of 1907, and it is mapped by Baldwin as of this date (see the map, Plate I). However, on his map it is shown as extending down past Puu o Keokeo on the *east* of that group of cones. Nevertheless, on the writer's short reconnaissance he went on horseback up between the flow of 1887 and the Kahuku branch of 1916 onto the ancient lava ridge that projects uninterruptedly eastward from Puu o Keokeo without crossing this lava stream. Hence it is clear that no part of this flow follows the course past Puu o Keokeo shown on that map. This upper stream did, however, pass down on the *western* side of Puu o Keokeo. While the detailed expression of its course, therefore (and of that of a contributory stream from a source below Puu o Keokeo), must await adequate topographic survey, the writer has *diagrammatically* sketched its course on the west of Puu o Keokeo on the map, Fig. 1, showing these southwestern flows. However, he has not attempted to indicate the long tongues which project southeastwardly over the great flat north of Puu o Keokeo, on account of want of data, and of the cartographic confusion that might result.

The 1916 eruption was of small magnitude compared with earlier action originating near its source. There are accumulations of ancient pumice far greater in depth and spread than that ejected at this time. The older double semicones round about are higher and greater and their gashes and fissure systems on a larger scale.

One such ancient source—whimsically designated in field notes as “the lunar crater” because of a steep and relatively high peak of riven blocks which stood near the center of its large, circular depression, or crater-like area—had been the spring of a lava flood *vast* in proportion to the recent flow. All about this old depression, except for its gap at the south, was a high rampart built of huge cinder blocks piled confusedly, and outward from the top of this a slope built of small cinders and pumice fragments fell away gradually.

Also the cones at Puu o Keokeo point to action of far greater magnitude at the time of their building than recently—greater than any action of historic date on the south flank of the mountain. These cones, however, are only a conspicuous group in the well-marked belt extending from the summit down the slope below them. Though perhaps these are the largest of all, there are others of comparable size, both above and below. The suggestion, therefore, attributed to the late S. E. Bishop, that Puu o Keokeo is a vent distinct from Mauna Loa, but subordinate to it, probably must be dismissed. This point, though a digression, is interesting and important, since it might be considered to bear on the question of the genesis of the 1916 eruption.

In connection with this same point it is worthy of note that the eruptions of 1868 and 1887 (and probably of 1907 also) were preceded by outbreaks of fumes and lava much higher up the mountain than their eventual heads of flow—action similar to that preceding the 1916 flow.

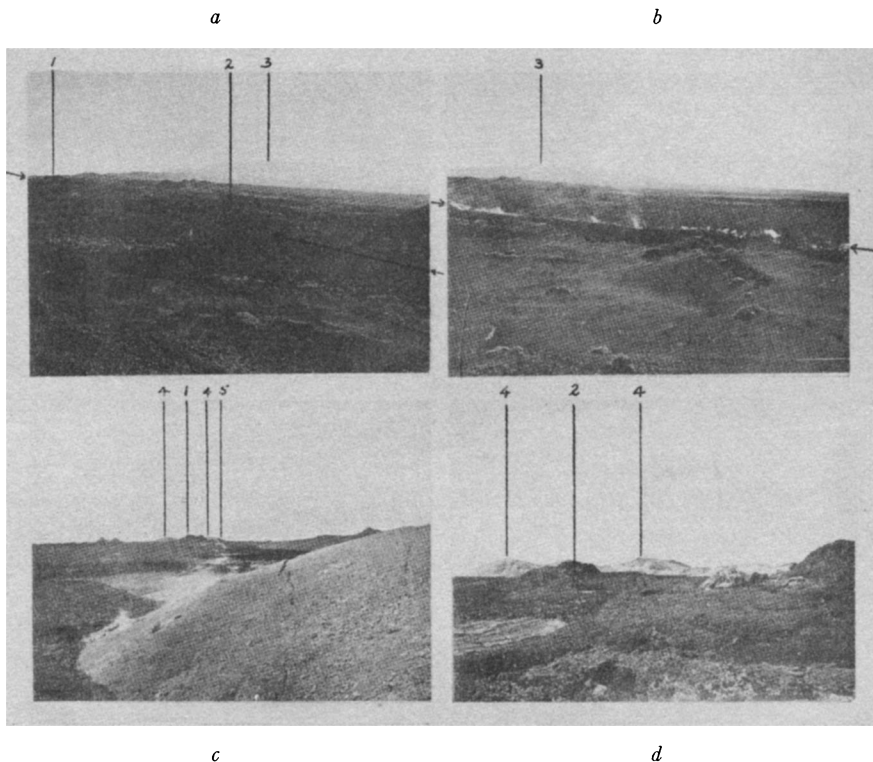
In 1868 such action broke out in the evening of March 26, with a further outburst in the early morning of March 27 “a little to the southwest of the summit,” followed by outflow from low sources, at the southwest on Kilauea on April 2, and at the south-southwest on Mauna Loa on April 7. This upper outbreak was very near the summit.

In 1887 the first outbreak was in the evening of January 16 at an elevation of about 11,500 feet on the southwest, and flow began, from a little below Puu o Keokeo, in the evening of January 18.

The exact places of these upper outbreaks were not mapped in either instance.

In 1907, on account of weather conditions adverse for distant seeing, only vague accounts were given. Nevertheless, mention is made, perhaps doubtfully, of an outbreak judged to be at the summit, preceding by a few hours the outbreak of flow lower on the flank.

Hence, though the places of outflow in several of these eruptions have been found suggestively near to Puu o Keokeo, still there is no doubt that the eruptive action in all cases extended far up the south flank of Mauna Loa beyond this group of old cones. Moreover, critical study of the distribution of these heads of flow develops no causal association with this as a center.



a, a view looking a little to the north of east from Puu o Keokeo, showing the flow source. The new rift line, indicated by arrows, traverses the middle ground obliquely. Note the gashed cones; also note the faint streak of fumes, line 3, near the mountain summit, 14-15 miles away—the source of the fume outburst of May 19. Line 1 indicates the larger cone at the chief head of the Honomalino stream. Line 2 indicates the largest 1916 cone at the chief head of the Kahuku branches.

b, a view from an old cone a little N.W. of the head of flow looking about N.E. at the northern portion of the new rift, indicated by short arrows at margin, marked by solfataric action. Note also the streak of fumes, and the light-colored area, at the source of the outbreak of May 19, line 3.

c, a view looking south toward Puu o Keokeo from the old cone at the head of the new rift. Note the slight curve in the line marked by solfataric action, with new cones beyond; line 1 indicates one of the larger new cones at the chief head of the Honomalino stream, line 5 indicates the small cone at the head of flow, and the lines 4 indicate Puu o Keokeo, $3\frac{1}{2}$ miles away. In the foreground is a freshly riven spur of the old cone.

d, a view from near the eastern edge of the new flow, looking S.S.W.—a detail of the source near its southern end, showing the cone at the head of the Kahuku branches; line 2, a short tongue of 1916 lava projecting eastward, and old surface in the foreground. A considerable fall of new, basaltic pumice partly covers both old and new lava here. The lines 4 indicate Puu o Keokeo.